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AIR VEHICLE TECHNOLOGY MODELING AND SIMULATION

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14. ABSTRACT

The aircraft design process is a complex, highly iterative, time-consuming process that contributes significantly to the overall engineering cost. Aircraft specifications, including performance, weight, cost, and other aspects, must be addressed to create an effective design. The multidisciplinary nature of the engineering process, which includes design, analysis, and manufacturing, follows a regimented path that is initiated by preliminary design, evolves into a preliminary design, and is followed by a detailed design for production. Many critical design decisions are made at the conceptual level where the least amount of information is available to assist in the design evaluation and tradeoffs.

The objective of this effort is the development of a comprehensive design environment for modeling and simulating the aircraft systems, seamlessly integrating different engineering processes. The system architecture will support a single underlying object-oriented architecture with demand-driven computation and dependency tracking that allows information to feed forward and backward among various engineering processes as the design evolves.

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Abstract

The results of a research effort investigating the development of a comprehensive design environment for modeling and simulating aircraft design methods, seamlessly integrating different engineering processes, is presented. The system described supports a single underlying object-oriented architecture. Methods were developed for describing conceptual level designs of fuselage components and component placement and wing geometry and substructure. First-order analysis modules for wing structural behavior and aerodynamic loading were researched and partial implementations completed for Phase I of this work. Recommendations are given for possible extensions and continuations of this work for Phase II.

Introduction

The cost of current military airplanes is divided into three roughly equal parts. One-third of the cost is avionics, one-third is engine and systems related, and one-third is structural material and manufacturing cost. While future Air Force technology goals call for reductions in the cost of all of these items through ambitious programs, none of these goals can be achieved independent of the others. For instance, a sharp reduction in cruise drag requires that airplane size be reduced significantly.

Geometrical size is related to the airplane mission and cargo requirements while weight is related both to geometrical size and structural design that combines the best possible combination of both advanced and low cost materials. The successful design of a light-weight aircraft structure can be severely constrained by requirements such as stealth, maintainability, reparability and, most important, affordability. Current materials and structural concept developments will probably reduce airplane and spacecraft structural weight fractions by only a few per cent.

To drastically reduce flight vehicle empty weight fractions, the structural procedures and methodology used to define loads and create internal structural forms must change and we must consider new aerodynamic configurations. These investigations require effective, rapid and reliable conceptual design tools that combine high analytical fidelity to reduce risk and visual and computational algorithms to enhance cognitive thinking.

The US has a well-entrenched design community that has produced innovative, successful designs. Despite this past success, drastic flight vehicle structural weight reduction is constrained by design philosophy and loads criteria that are the result of 90 years of experience with metals. The process itself is cumbersome and does not take full advantage of progress in information science and technology. Composite materials, such as inexpensive fiberglass and more expensive graphite tape and cloth, might provide smaller structural weight fractions that, from a systems perspective, are not expensive. In addition to their low weight, composite materials can provide tailored surfaces for low observables and may sometimes provide low cost alternatives to metallic designs.

New software design architecture supporting design automation and optimization, integrating reliable software, can assist design engineers to creatively explore the "what if" of conceptual design and to select those designs with merit while quickly discarding those with flaws. Two features are required to overcome the limitation of the present design process: ease of use to stimulate cognitive thinking; and, a process/knowledge modeling capability that captures concepts and integrates them effectively at an earliest possible time in the conceptual/preliminary design process.

Integration includes the ability to visualize, modify and take advantage of the tailorability of advanced materials and the ability to design efficient load paths and materials use for conventional materials. Complex trade-offs between weight/performance, manufacturing, and maintenance must be addressed reliably beginning at the materials level to attempt to capture their best properties and minimize their limitations.

The design of advanced composite structures is clouded by the fact that advanced composites are both a material and a microstructure, designed for optimal load path efficiency. This efficiency depends significantly on the fact that some important external loads are affected by flexibility of the structure. The capability to design load paths at the micro level is as important as the material's low weight. The X-29 research aircraft was the first to orient or "tailor" advanced composite directional strength and stiffness to prevent wing aeroelastic divergence and adverse interaction between the wing bending and aircraft flight mechanics modes. This so-called "aeroelastic tailoring" is a major advantage of advanced composite wing and tail structures and is an essential feature of composite structures that must be captured at the conceptual level.

The repetitive, iterative nature of flight vehicle design and the conflicting requirements for performance and affordability present a challenge to provide a comprehensive design system to integrate the various engineering stages. Capturing and modeling the engineering philosophies as related to the design evolution from concept to production details must be done to enable quick response to changes in designs, materials, and processes. Automating and integrating the various engineering cycles will speed the design process and provide high fidelity guidance for designers to interact across disciplinary barriers and to assess viability of the design and to define and to reduce economic risk.

Design requires a strategy to determine the exterior shape and also how to lay out the interior arrangement of structure and contents. Aerospace structural design demands a sophisticated analytical capability, coupled with information technology that provides a highly visual level of interactivity. This allows designs to be evaluated and changed when design inadequacies are revealed or modified when design superiority is identified.

The effective and perhaps optimal placement of load bearing material/structure inside an aerospace vehicle or platform is required to reduce weight and cost. This layout is traditionally delayed at the conceptual design stage. This delay later creates problems such as missed weight targets, decreased performance and cost over-runs. This synthesis problem can be addressed by a combination of theory and computer simulation. This strategy requires strong creative input from the computer so that it acts as the simulation device to interact with the experienced human designer who provides the creative engine that drives the design process.

Design of airplanes is generally characterized by the requirement to define the weight of the airframe components as accurately as possible, even in the initial stages of the design process. For this purpose empirical relationships based on statistical analysis of existing structural databases are widely used. However, this approach can not be employed to design structures which differ radically from existing, historical prototypes. An example is the amphibian aircraft whose planform is shown in Figure 1. This aircraft is a radical design whose fuselage is a major lifting body component and whose loads differ markedly from conventional designs. There is no reliable database for this weight estimation.

Design Architecture and Framework

The overall objective of this research (Phases I and II) is the development of a comprehensive design environment and framework for modeling and simulating aircraft systems that seamlessly integrates different engineering processes. This framework covers not only the accurate definition of the external shape on which lift and drag depend and the arrangement of internal contents in a straightforward manner, but it also includes the preliminary sizing of structural elements that tend to drive the weight of the vehicle and tend to influence the size of critical loads.

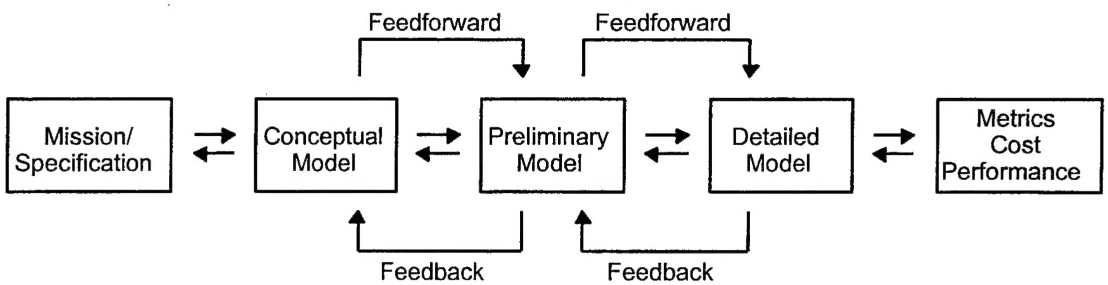

Figure 1: Design Process

The system's framework will support a single underlying object-oriented architecture with demand-driven computation and dependency tracking that allows information to feed forward and backward among the various design levels and engineering processes as the design evolves.

The proposed framework has two foci:

1) constructing and linking together conceptual, preliminary, and detailed models

2) seamlessly integrating engineering processes and tools.

In Phase I, the system architecture functional specification was studied, developed, and then completed. This architecture includes important aspects of conceptual and preliminary phases of aircraft design. The fundamental stages of the design evolution and the related engineering processes that drive the design were identified. Initial assessment of the various iterations among the different model representations was done to capture the process design evolution.

The system architecture that resulted is based on a modular framework; each module focuses on an engineering discipline or component design application. A limited prototype was developed to illustrate the design process; this prototype focuses on wing structure conceptual and preliminary design and analysis and its use was demonstrated. Preliminary versions of two modules were implemented. These modules focus on early geometric configurations and preliminary structural and aerodynamic analyses. In addition, manufacturing process planning and cost estimation modules have been studied; limited implementations have been developed but not yet integrated. The architecture has

been reviewed by members of the Air Force Research Labs Air Vehicle Directorate (AFRL) in collaboration with Lockheed Martin Tactical Aircraft Systems (LMTAS).

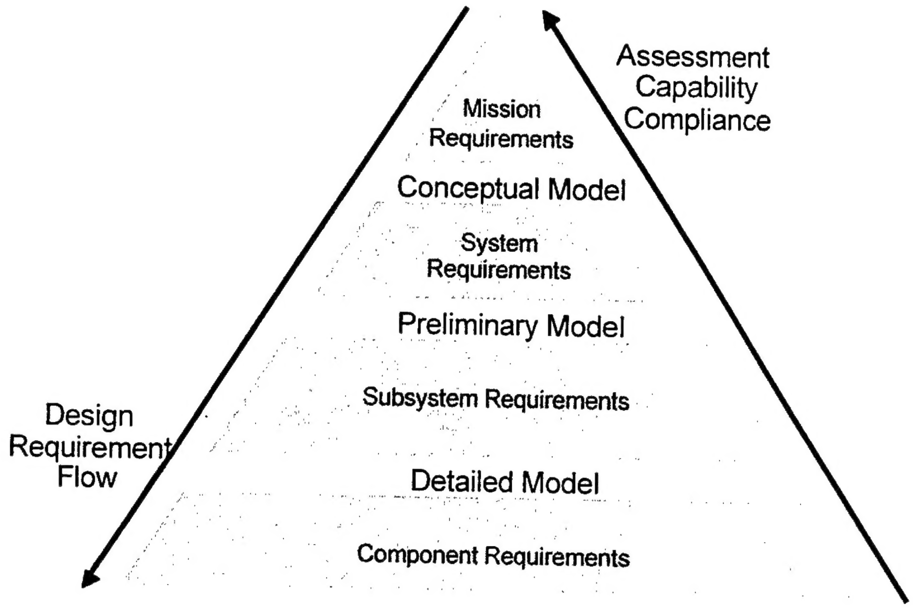

Figure 2: Model Layering

The architecture provides a framework supporting the seamless integration of various tools and applications in the aircraft design process. An appealing feature of this architecture will allow design tools to evolve or be updated without requiring changes to the interface within the architecture. Multiple tools may be made available to the designer that serve the same purpose. This will allow designers to select the appropriate level of analysis for their particular task. It will also allow for mixed design modes, with some analyses performed at a low-order conceptual level while others are done at a high fidelity, preliminary level.

Phase I Objectives

The purpose of Phase I of this project was to determine the requirements for and lay the foundation for the framework of a system allowing for the design of aircraft through the conceptual and preliminary levels.

The stated objectives were:

1. To research the analytical requirements for conceptual design and investigate the concepts important to components used for conceptual design. The analytical model would concentrate on the wing structure.

2. To plan the architecture for a preliminary design model considering the different requirements of conceptual and preliminary design. Again, the wing structure would be emphasized with consideration given to stiffness, stress, and mass distribution. Links to higher-order analyses than those considered for conceptual design would be investigated.

3. To research the development of analytical procedures to study the aeroelastic behavior of wing structures. This would emphasize the development of analyses to link the structural and aerodynamic behavior of wings. The model would allow studying the interactive between materials selections and aeroelastic behavior.

4. To develop a framework linking the conceptual and preliminary aspects of aircraft design. This would involve the selection of a development environment for creating the aircraft models. Also, the framework would allow for mixed-mode designs in which one part of the required analyses could be done at the conceptual level while others might be at the preliminary level. This capability would allow the designer to tailor the design process for specific needs.

5. To explore the use of knowledge-based systems for conceptual aircraft design. This would involve design rules integrated directly into the aircraft model.

6. To study the requirements for graphic visualization of results to improve the designer's understanding of the process.

7. To develop a plan for a more advanced analytical model incorporating such aspects as improved analysis, manufacturing processes, and advanced design rules.

Many of these objectives were accomplished with the development of a "preliminary" conceptual model for aircraft design. This model incorporates aspects of geometry required to define the fuselage components and wing structure. Analytical modules are incorporated into the model to predict the aerodynamic loads on wings and the response of wing structures to applied loads. The modules provide the basis on which aeroelastic analyses may be built.

This model provides a framework on which the project may be expanded and enhanced. The conceptual design and analysis elements can be "unplugged" and replaced with preliminary-level modules.

A description of the model developed to explore the Phase I objectives follows.

Phase I Aircraft Design Model

In order to investigate the objectives specified for Phase I of this work, a model was developed which incorporates, at least at the proof-of-concept level, many of the elements which will be required by the complete system. This model incorporates geometric descriptions of fuselage components and layout and the wing aerodynamic surfaces and structures. First-order analytical models for aerodynamic load determination and structural response to loads for the wings were incorporated.

The "preliminary" modules that comprise this model were developed to explore the concepts involved in conceptual and preliminary aircraft design. As such, they lay the foundation on which further developments and enhancements in Phase II will be placed.

The components of the conceptual model itself can be divided into three categories: geometry, analysis, and mission simulation. The geometric and analysis modules have been integrated into a tightly-linked development model.

Aircraft Model Geometry

Before any design work or analysis can be performed, a system needs to be available to describe the geometry of the aircraft. This requirement fits into Objective 1, but is necessary for most of the other objectives and will be used throughout all phases of the project. To provide a basis for the rest of the Phase I work and to create a framework for later phases, a simple model was developed which allows the designer to describe critical aspects of the fuselage layout and wing structure and aerodynamic shape.

This limited implementation addressed some aspects of the design scope of wing surfaces and substructure layout. This methodology will provide the basis of a conceptual design module to address configuration and layout of major vehicle components such as payload, engines, ducts, and fuel-containing regions. The following discussion outlines the procedure that was developed and some of the aspects of the "proof of concept" model.

Configuration and layout at the conceptual design stage requires two interdependent activities. The first focuses on the initial layout of the major components and their bounding (simplified-shape) envelopes. The second focuses on the outer surface definition of the fuselage and wings, as well as inlet surfaces.

The layout of the components requires a set of coordinate systems for positioning and orientation all within a single coordinate frame. The fuselage components are defined in terms of a number of cross sections with position and dimension properties. Inlet surfaces are defined in a similar fashion. The dependencies and constraints among the fuselage and the components could be defined by two methods: 1) the outer surface dimensions are directly/indirectly associated with the size of the components and their positions, or 2) the size of the components and their location could also be dictated by the fuselage, wing, and inlet locations and shapes. The first approach is based on an inside-to-outside design approach, the second on an outside-to-inside design approach. A design could consist of a mixed set of approach-defined constraints.

For layout and configuration, components may be placed anywhere within the model and their positions can be specified relative to other components or to the aircraft coordinate frame. Each component may have its own coordinate frame. Once the positions and orientations are specified and their dependencies set, moving the reference component will update the position of any dependent components.

For example, an engine may be placed such that its station position is a specified distance behind the payload bay but with its spanwise and vertical positions independent of the payload bay. If the station location of the bay is changed, the engine will follow it; but, if only the vertical position of the payload bay is changed, the engine will be unaffected.

The fuselage outer surfaces are defined by a set of cross sections each having size, shape, and position properties. Once the outer surface of the fuselage is defined, the initial layout of substructure (bulkheads, stringers, etc.) is identified with constraints to account for the space required by the components (payload, engine, etc.). Additional clearance requirements for the layout of subsystems (electrical, fuel, etc.) will also be considered. Mixed dependencies can be set. For example, the size of certain components is dictated by the available space within the surface boundaries or the surface shape in a certain region is dictated by the shape of the components within that region and the subsystem layout.

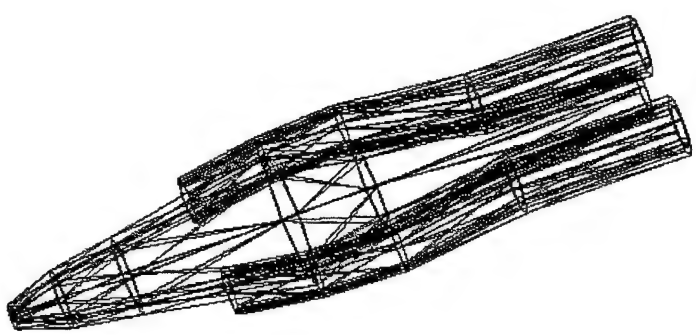

Figure 3: Aircraft Fuselage

In addition to the default reference position which all components possess, it is also possible to define new reference positions. These reference points can be located in or on any component or relative to the aircraft coordinate frame. Thus, if a wing is to be located with its root on the outer bound of the payload bay, a reference point can be located on that boundary and the wing oriented relative to that point. If the bay moves or changes size, the wing will move appropriately.

Some components, such as fuel tanks and ducts, can be specified by connecting cross-sections. These cross-sections are placed in the same manner as other components (using relative positions). In addition, the cross-sections of pre-existing components may be used. If any of the cross-sections move (due to the changing position or size of the components to which they are anchored), then the duct-like components will automatically adjust.

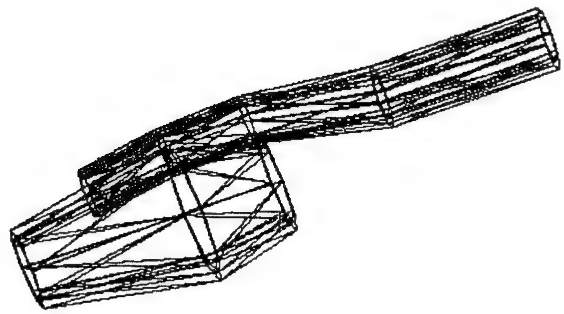

Figure 4: Payload Bay, Engine, and Inlet Duct

Once the components are placed, their outer boundaries can be used to establish the constraints on the construction of the fuselage outer skin. Minimum clearance constraints can be imposed for sizing the outer surface model to allow for the subsystem layout and substructure sizing.

The wing geometry is not handled with the same type of configuration as the fuselage. However, the wings are placed in the aircraft in the same way as fuselage components. The wings are divided into panels with each panel described by a root and tip airfoil and properties such as twist, dihedral, and sweep.

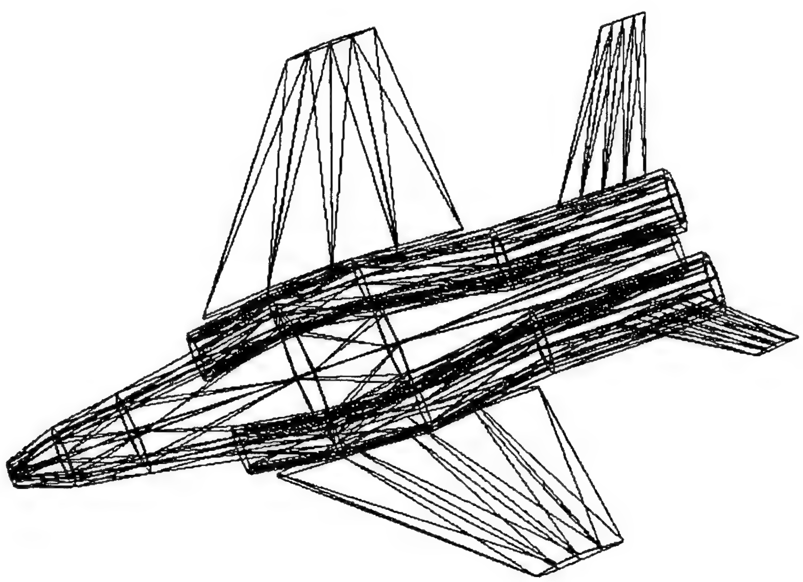

Figure 5: Aircraft Fuselage and Wings

In addition to the upper and lower skins, the wing structural components are modeled. The substructure can consist of traditional ribs and spars (Figure 6). These substructure components do not need to follow straight lines (or a traditional grid structure). Curved spars can be modeled (Figure 7). All wing structural components are placed and described with respect to a wing reference surface (the mid-surface).

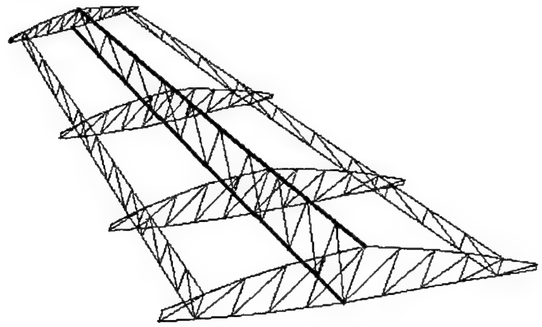

Figure 6: Wing with Rib and Spar Substructure

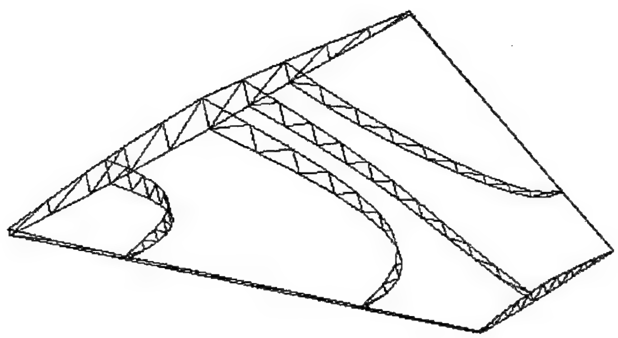

Figure 7: Wing with Curved Substructure

Since the Phase I model was created to demonstrate concepts rather than provide a complete design environment, several aspects will need to be considered for expansion in Phase II:

a. Multi-panel wings: During Phase I, a framework plan was developed to allow wings to be described as a series of panels. This description allows each segment to have its own varying chord and thickness distributions, sweep, and dihedral. For the model implementation, however, wings were limited to a single panel. For Phase II, this limitation will need to be removed. The model will be created to allow for multiple-panel wings.

b. Fuselage design: For Phase I, a method was developed to allow the aircraft fuselage layout to be designed by placing the internal components. Each component has an inner and an outer surface; the outer surfaces can be combined to form the outer fuselage surface. Phase II will require implementing the method developed in Phase I. The component surfaces will provide a model of the internal space occupied by the components as well as the outer surface. Using these two parts of the model, the space between the components and the outer fuselage can be modeled. This space would be occupied by structure and subsystems.

First-Order Structural and Aerodynamic Analyses

During Phase I, considerations for first-order analysis centered on wing behavior. Procedures were studied to predict aerodynamic loads and structural response to applied loads. A limited implementation with a focus on wing analysis was created. Preliminary analysis models were researched to develop for computing loads and wing deflection. The analysis models are closely tied to the geometric models of the air vehicle. Two analysis modules have been considered:

1) aerodynamic load analysis, and

2) structural analysis.

Aerodynamics

The first-order aerodynamic analysis model is based on vortex-lattice theory. The surfaces (wings) are divided into four-sided panels. These panels are divided into elements from which the corresponding vortex lattice will be generated (Figure 8 and Figure 9). The model can handle large numbers of panels and individual wings can be composed of more than one panel.

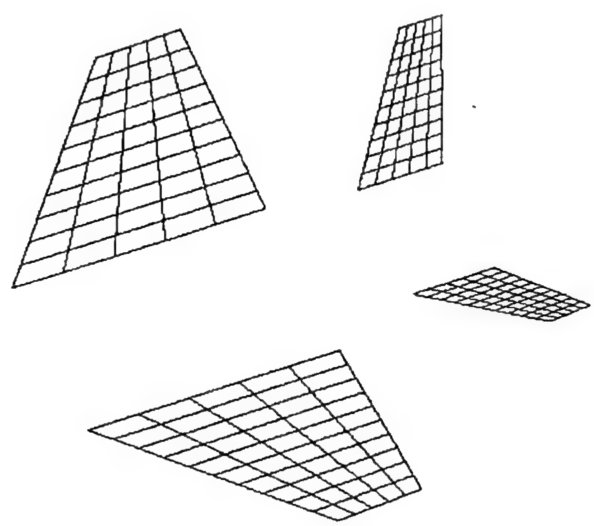

Figure 8: Aircraft Vortex-Lattice Elements

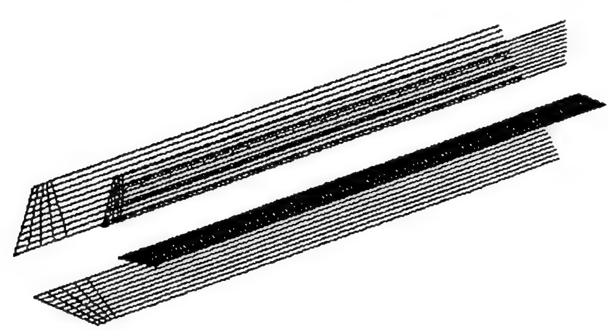

Figure 9: Aircraft Vortex Lattices and Trailing Vortices

Using the panel lattices, a solution can be found for lift and induced drag (and the corresponding lift and drag coefficients). The lift distributions for a single panel and for the aircraft are shown in Figure 10and Figure 11. The solution shown assumes that the panels are alone in the freestream but influence each other; the fuselage is not modeled. The model developed for this work will allow the inclusion of interference panels to model the fuselage and provide a more realistic lift distribution. It will be possible to solve for the lift and drag of individual panels in the free stream, without the influence of the other panels. In general, however, this result is not as useful as the solution with the influence of all panels taken into account. The analysis solution can be presented for individual panels or the entire aircraft in numerical and graphical form.

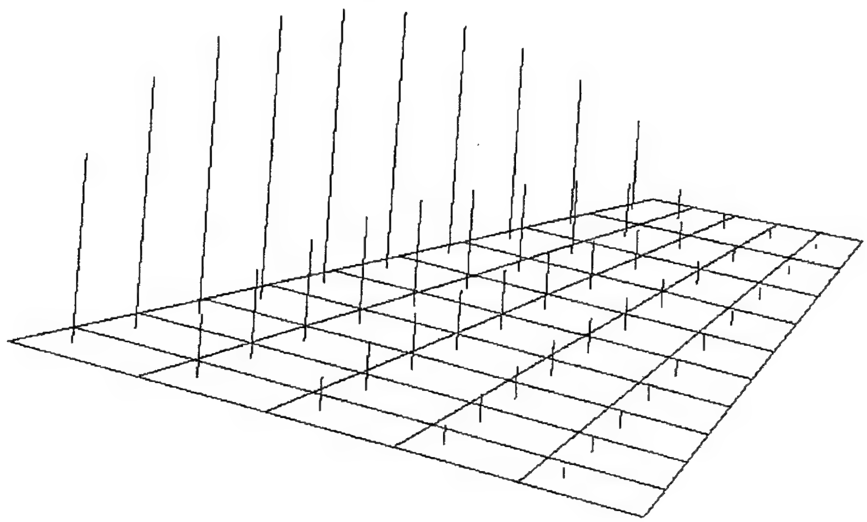

Figure 10: Lift Distribution on Single Wing Panel from Aircraft Vortex-Lattice Solution

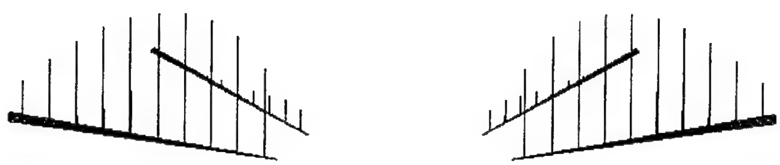

Figure 11: Aircraft Lift Distribution from Vortex-Lattice Solution

The panel grids shown in the figures are laid out in a uniform pattern. The model will be created so that it can be modified to allow information on wing control surfaces to affect the grid pattern. When implemented as part of Phase II, this will allow the grid to be adjusted to fit the control surfaces and then relocated to match the control surface deflection. The resulting aerodynamic loads, which will be fed to the structural analysis, may be non-symmetric due to uneven control surface deflections (as with ailerons).

The aerodynamic solution may be created to be linear with respect to the free stream conditions–the influence of the vortices on each other is independent of the free stream. This situation develops when the panel trailing vortices (wake vortices) are independent

of the angle of attack. If the wake depends on the angle of attack, then the vortex influence matrix must be recomputed for every angle, slowing solution times. Part of the Phase II development will be to study the effects of wake movement on the solution and solution times and include this behavior if necessary.

Structural

During Phase I, a procedure was developed to model the deformation of wing structures under applied loads. A limited implementation of this procedure was built into the Phase I model; the full procedure will be implemented as part of Phase II. A description of this model follows.

The structural analysis model is based on assumed global deformation fields. Structural components within the conceptual model are represented by surfaces. A mesh model is derived from the surface model. The mesh elements are triangular as shown in Figure 12. An overall structural stiffness matrix is computed representing the skin and substructure elements. The focus of this approach is on computation speed. The deformation of a single panel with arbitrary loads should be computed in less than one minute. Most of this time is spent computing the panel stiffness matrix; subsequent solutions with different applied loads are very fast. A deformed wing panel (corresponding to the structure shown in Figure 6 is shown in Figure 12.

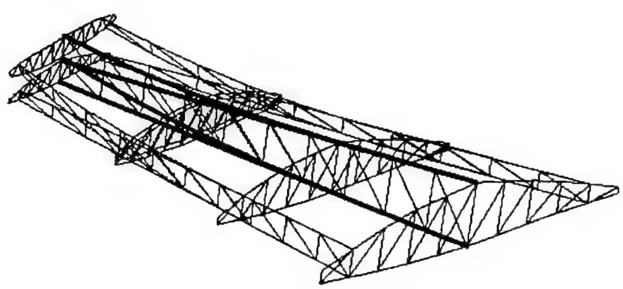

Figure 12: Deformed Wing Substructure

One and two-dimensional structural components will be modeled. The two-dimensional components include skins and substructure. The model will allow for substructure in the form of conventional ribs (chord-wise) and spars (span-wise) or unconventional structures which follow any path within the wing. The two-dimensional components will be modeled using a triangular mesh. The stiffness of the mesh elements is based on a finite element formulation and three element types are available: shell, membrane, and shear-only membrane. For each two-dimensional component, a global stiffness matrix is computed based on a set of degrees of freedom describing the displacement of assumed deformation modes. These matrices are summed to produce the overall stiffness matrix for the wing. The thickness and material properties of each two-dimensional structure will be allowed to vary along the chord and span (for skins) or the length (for substructure).

One-dimensional structural components will be modeled using rod elements. These will typically be used for substructure cap strips or skin panel stiffeners. Similar to the two-

dimensional components, they will be modeled by being broken into elements along their length, with the behavior of each element modeled using a finite element based formulation. Based on these elements and the overall assumed displacement modes for the structure, a global stiffness matrix is formulated for each one-dimensional component. These matrices are summed into the overall structure stiffness matrix along with the two-dimensional components. The cross-sectional area and material properties of the one-dimensional components will be allowed to vary along the length of the component.

The geometry of all wing structural components (skins and substructure) will be defined with respect to a reference surface (typically at or near the wing mid-surface). This surface is based on the overall wing geometry (taper, twist, dihedral, etc.) and may be queried for information such as position and tangent and normal vectors. Positions on the surface are defined in terms of parameters (u,v) running from 0 to 1 along the span (inboard to outboard) and chord (leading to trailing edge).

Wing skins will be defined over a range of wing position parameters (u,v). The skin meshes are rectangular in the parametric space. The nodes used to generate the skin meshes will be found by projecting from the reference surface at the appropriate position along the reference surface normal to the wing surface (based on the airfoil shape). These nodes will then be used to form the triangular mesh used for structural analysis.

The positions of substructure components (ribs, spars, and stiffeners) will be specified by a curve defined in the two-dimensional parameter space of the reference surface. A single parameter will specify a position along the length of the component. From reference surface positions and normals based on this parameter, nodal positions on the wing outer surfaces (or within the bounds of the wing outer surfaces) can be found. The model will allow these components to be placed using two methods, linear and curved. The linear components will be positioned based on a linear function in the wing parameter space. These components are linear in the final structure only when they run along lines of constant chord or constant span position. The curved components will be specified as bezier curves in parameter space. End points and tangent vectors are specified for each end of the substructure. New objects representing other geometries can be defined based on the ones provided in the model. The ability to specify substructure along curves allows for the investigation of unconventional structures.

The implementation of this model for Phase I is limited to isotropic materials. Provisions will be made to change the material model used to define element properties. Possible choices will include isotropic and composite materials.

The structural analysis methods researched in the course of investigating Phase I issues have only been applied to wing structures. As part of Phase II, they will need to be expanded to handle fuselage structures and the wing/fuselage interface. This will require new methods for meshing (node generation) and a new formulation of displacements for the assumed displacement mode model.

Mission Analysis

Two methods were developed to provide input to the design process based on aircraft mission analysis. These will be used to provide basic sizing information to the designer

at any level, including conceptual. These analyses will be used to drive design parameters at the conceptual phase.

The first method was developed by team members at Purdue University; this method uses a traditional sizing method where the requirements are mapped onto a design space that becomes a so-called "constraint diagram." This mapping is based on empirical equations and trend data from stored data bases. Analysis results are displayed on the screen as the program computations iterate through the mission to determine the amount of fuel required and aircraft size features. It also allows the user to specify constraints such as required runway length, climb rate, or cruise altitude and then account for the ability of the design to fulfill these mission requirements.

The second mission analysis scheme is based on trajectory analysis and is being developed at AFRL with assistance from TechnoSoft. By specifying a flight path, this system can be used to determine aircraft structural loads.

Summary of Phase I Aircraft Design Model

Many of the objectives for Phase I were either met with the planning and development of this model or have been researched by using the model. The geometry of the aircraft for a conceptual-level model can be laid out using a process which can be developed by building upon that created for this model. This will allow the description of the fuselage geometry based on constituent components and the wing substructure.

The framework developed for the conceptual model is applicable to the preliminary model. Many model components, such as the structural and aerodynamic analysis modules, will be able to be swapped between the different levels. These two modules, in particular, can be used to study the aeroelastic behavior of the wing structures.

The Phase I model contains some components for the graphical visualization of the model. The aircraft geometry is displayed as a full, three-dimensional model which can be viewed at any orientation or position. The results of the analyses can be displayed. The deformation of the wing structure can be shown as a picture of the actual deformation (with the undeformed structure displayed simultaneously for comparison). The aerodynamic loads can be displayed as a distribution over the wing surface. These visualization tools provide a clear indication of the usefulness of providing a direct, immediate display of the modeling process and analysis results to the designer.

During our research we also identified advanced structural design methods that can be easily incorporated into AML. These methods are finite element based and are capable of furnishing the design team with data on load paths and critical weight items. This method is unique in that it uses advanced analysis at an early point in the process where it can influence design decisions and can define weight critical items so that less reliance has to be placed on data bases that may be inadequate to advanced design concepts. This incorporation of internal aircraft structural/component design capability at a high level is a key feature of the AML approach and cannot be found elsewhere in the United States, either as a research tool or as an industrial process.

Recommendations for Phase II

The purpose of Phase I of this project was to determine the requirements for a system to enable aircraft design from the conceptual through preliminary levels, design the modeling framework required to model that process, and develop a limited implementation of the framework. Phase II work will be required to extend this framework, filling in the gaps left in the Phase I model.

Several specific areas have been identified which require either continued to additional efforts to complete. The work completed in Phase I leads to the following recommended areas for further development in Phase II:

1) Conceptual design,

2) First-order analysis,

3) Topological design of skin and substructure,

4) Higher-level analysis and detailed model development, and

5) Optimization, sensitivity studies, and design of experiments.

Conceptual Design

A major goal of this research is the development and implementation of an engineering framework architecture to enable the layout, configuration, and sizing of major aircraft components. The focus will be on the fuselage, wings, inlets, engines, and payload.

During Phase I, the emphasis was on describing the overall geometry and internal structure of an aircraft wing. A limited implementation was developed. In addition, a limited system for laying out fuselage components was created. For Phase II, these systems need to be completed and the architecture expanded to include the layout and configuration of overall vehicle components, component surface boundaries, and substructures.

The architecture should be implemented as part of an object-oriented framework that supports a sophisticated interactive 3D graphical system that enables manipulating the size and position of aircraft components.

First-Order Analysis

During Phase I, first-order analysis modules for wing structures and aerodynamics were researched. Limited implementations were created. These modules need to be expanded and linked as part of Phase II. The aerodynamic analysis can be used to predict the loads on the wing structure. This input will allow more accurate sizing of structural components to occur at the conceptual level, allowing for more accurate predictions of vehicle weight and for more of the initial design work to be done before required more advanced, finite-element-based analyses.

Phase II work should include the completion and expansion of these analysis modules.

Topological Design of Skin and Substructure

Structural design and sizing is an iterative process. Augmenting the design process with a computer-based algorithm for shape optimization presents several advantages. Elements of interdisciplinary optimization can be included during the conceptual phase and the number of design iterations can be reduced. These algorithms would address issues related to structure configuration based on materials and manufacturing processes and their limitations in addition to the loads being transferred. For example, the location of a spar within the wing substructure is a critical decision in the early design stage. Beside its location and orientation, its detailed shape is dictated by the loads applied to its body. Prior to running a finite element structural analysis, the internal structure must be detailed. Present practices require major efforts to define the substructure shapes using performance-estimating techniques for structural weight and sizing.

A potential area for expansion during Phase II would be the development of special algorithms for structural layout and stiffening based on load paths and shape constraints. These algorithms can be tightly integrated with the overall framework to enable the layout and sizing of structure early in the conceptual design stage. These algorithms will be based on solid theory following an innovative scientific process that still requires finite element model s but does not require the computational power of a standard finite element solver and is focused toward the overall shape definition, sizing, and layout of the structures (Komarov and Weisshaar).

Augmenting the design process with the generation of load path information and design information allows geometrical shape and topological optimization. As a result, the number of design iterations can be reduced and the final quality improved. These algorithms will address material-selection issues and provide options to address cost/affordability of manufacturing. The goal would be to reduce the effort required to define substructure shapes by using performance-estimating techniques for structural weight and sizing.

Higher-Level Analysis/Detailed Model Development

The first-order analysis described above and partially implemented as part of Phase I enable the initial layout of the overall aircraft configuration and sizing of substructures. For Phase II, links to higher-level analyses should be included. These finite-element-based analyses will allow the integration of modeling strategies to reduce the number of cycles required to decompose the model and generate the finite-element models for the next iteration. The organization of the overall framework can be designed to allow the designer to switch and combine levels of analysis (such as a fast, first-order aerodynamics solution combined with a higher-level structural analysis); the analysis package can be tailored to the requirements of the individual designer.

Detailed analysis during Phase II could focus on 1) integrated parametric and object-oriented finite element modeling and meshing automation and 2) seamless integration of finite element solvers with the capability to automate the input creation and to retrieve and use the results for detailed design.

Optimization/Sensitivity Studies/Design of Experiments

A fundamental difficulty with a multidisciplinary environment is finding a way to compare various parameters of a design concept and to interpret the results of various analysis processes in a way which permits combining them for the assessment of total design performance. To handle the problem realistically, a framework should be developed which allows for dependency tracking and sensitivity analysis as part of a synthesis and optimization module. This framework should automatically track the dependencies among various engineering models and processes.

During Phase I, a limited implementation of a suite of objects was developed by the staff at WPAFB in conjunction with TechnoSoft to study sensitivity analysis and optimization. These objects allow for trade studies to be performed based on models represented by the object-oriented framework architecture by tracking and cross-referencing various parameters within the model. These parameters could be assigned a range of properties in which the system will attempt to converge on a feasible combination of parameters which provides the optimal solution.

Part of the work in Phase II could be to improve the implementation of these methods and fully integrate them into the overall design model, making them available at all levels of the design process.

Summary and Conclusions

During Phase I of this work, the processes involved in the conceptual and preliminary design of aircraft were investigated. An framework architecture was researched to implement these processes as part of a single, cohesive design environment. A model was developed to test the concepts encountered during the research.

The analytical and design requirements for the conceptual design of aircraft were investigated. A model was developed which allows the designer to define the geometry of the aircraft. For Phase I, this model was limited to the placement of fuselage components and the specification of wing geometry and substructure.

First-order analytical models were developed to investigate structural behavior and aerodynamic loads. These models concentrate on the wings as part of Phase I. They may be extended as part of Phase II. An extension of the structural and aerodynamic models from Phase I can be used to investigate the aeroelastic behavior of wings and determine the interactive between material and structure design choices and wing response.

While developing the architecture to support conceptual level design and first-order analytical models, the framework was planned to allow for the integration of higher-order analyses. These new analytical models will support higher-fidelity methods. The framework has been designed to allow the user to select the level of analyses that are performed for different parts of the model (i.e., using a first-order aerodynamic model to determine the loads used as input to a higher-order structural model).

The framework for the model was developed in AML, an object-oriented design language which incorporates features which simplify the development of the aircraft design model. These include features such as demand-driven computation and dependency tracking. This environment is a crucial contribution to the ease with which the various aspects of the design model have been integrated. The environment provides built-in capabilities to implement knowledge-based concepts which may be developed and integrated into the design process. Its graphical capabilities were used to display aircraft components during the design process and the results of the first-order analyses developed under Phase I.

Part of Phase I involved planning the extensions to the model which should be incorporated in the development process under Phase II. These involve completing and enhancing the conceptual aspects of the Phase I model such as the component design process and first-order analyses. In addition, recommendations have been made to extend the analytical models to higher-order analyses to be used in preliminary design work and, further, to add modules capable of being used for optimization and sensitivity studies. Processes have been outlined to implement the topological design of structure, providing the user with load information that can be used to create structural models earlier in the design process than previously possible.

The model implemented as part of Phase I demonstrates the capabilities that can be made available to the aircraft designer when using a fully integrated design environment. There can be rapid feedback of analytical results based on first-order analyses early in the design process. This will allow better design decisions to be made early in the design process,

reducing or eliminating the number of costly (or impossible) redesigns required later in the design process. The completion of these capabilities as part of Phase II, as well as extensions added for higher-level analyses and design concepts, will provide the designer with an enhanced environment for aircraft design.

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